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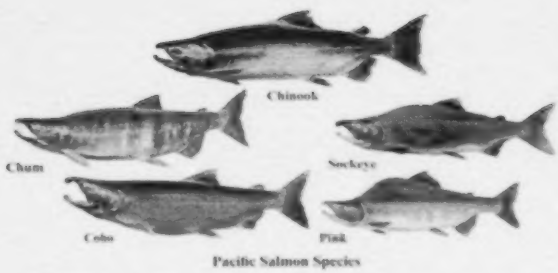
Pacific Region

Canadian Science Advisory Secretariat
Science Advisory Report 2016/049

REVIEW AND EVALUATION OF FISHING-RELATED INCIDENTAL MORTALITY FOR PACIFIC SALMON



Adult morphologies of the five Pacific salmon species considered in this review of fishing-related incidental mortality. (Source: Georgia Strait Alliance)

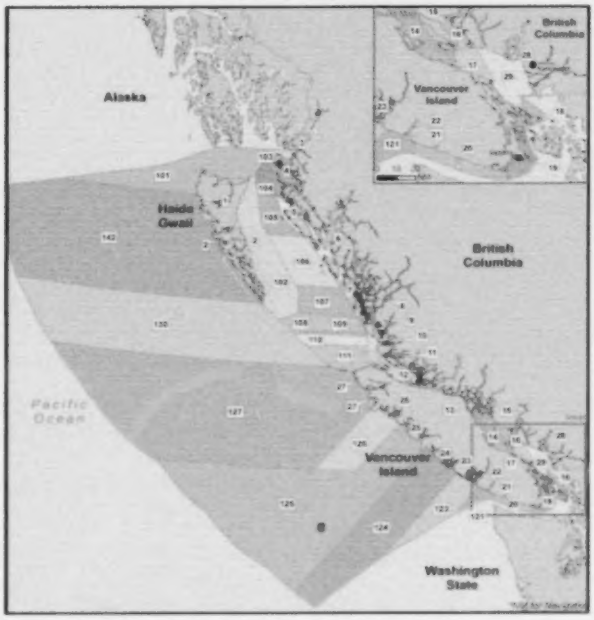


Figure 1. Marine fisheries management areas of British Columbia. This work also includes relevant fisheries from the Fraser River watershed (not illustrated).

Context:

Properly accounting for fishing-related incidental mortality (FRIM) is integral to the calculation of total mortality, which in turn can improve estimates of exploitation rate and stock size that are used to assess and manage Pacific salmon. FRIM includes several sources of mortality: mortality prior to capture (e.g. depredated and escaped fish), mortality at time of capture (i.e. fish—other than retained catch—that are dead or die upon capture), and mortality post-release. Issues with the FRIM rates currently used in stock assessment analyses and fisheries management plans for Pacific salmon include the variability in the length of time mortality is monitored after a fishing encounter, the need to include fishery context-specific information (e.g. water temperature), and the current lack of a transparent, objective and reliable process to incorporate new research as it becomes available. Addressing these issues will improve estimates of FRIM, which will then reduce the uncertainty in predicting the impacts of different fisheries. An improved understanding of factors that affect FRIM will aid in post-season accounting of both natural and fishing-related mortality. In addition, the evaluation of all types of non-retention mortality will improve Canada's commitment in the Pacific Salmon Treaty to quantify total mortality.

Fisheries and Oceans Canada (DFO) Fisheries Management has requested that Science Branch conduct a review of the available literature pertaining to factors relevant to FRIM of Pacific salmon and to provide

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recommendations on a process to derive and/or modify current FRIM estimates for use in the assessment and management of Pacific salmon fisheries.

This Science Advisory Report is from the June 6-7, 2016 regional peer review on the Review and Evaluation of Fishing-Related Incidental Mortality for Pacific Salmon. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Fishing-related incidental mortality (FRIM) includes all mortality associated with fishing activities, beyond the mortality accounted for in retained catch. FRIM includes estimates of mortality rates for fish that encounter fishing gear but are not captured (e.g. escape mortality), that are dead upon or die during capture (e.g. on-board mortality), or that die after release (e.g. post-release mortality).
- FRIM rates are used by fisheries management and stock assessment programs in the accounting of total mortality estimates of Pacific salmon. Issues with the FRIM rates currently used in stock assessment analyses and fisheries management plans for Pacific salmon include the variability in the length of time mortality is monitored after a fishing encounter, the need to include fishery context-specific information (e.g. water temperature), and the current lack of a transparent, objective and reliable process to incorporate new research as it becomes available.
- A novel, fish-centric approach was developed to better understand the factors that drive incidental mortality associated with fishing and to place the reviewed literature within the context of FRIM. An extensive primary literature review was conducted and relevant metadata were documented in updateable, searchable tables. Using this approach, detailed written reviews were provided for more than forty factors that can influence FRIM, with each factor assessed via a biologically-based mechanistic framework.
- An interactive catalogue was created to house empirical evidence of mortality estimates relevant to FRIM of salmonids. The protocol used for the standardized search and data extraction of the relevant primary and grey literature was documented to facilitate the future inclusion of new information, as requested by Fisheries Management.
- Collectively, the factor analysis and mortality data catalogues provide a scientific evidence base for making future decisions about FRIM that are rigorous, objective and transparent.
- A synthesis of the factor analysis and the different components of FRIM was conducted to better describe and predict FRIM. Five factors (capture time, handling, injury, water temperature and predators) were selected for characterizing the risk of FRIM based on two steps: first, a review of the supporting evidence and biological mechanisms relating the factor to fish response; second, a review of the magnitude of the response and utility of the factor for generating FRIM rates. In addition, the five factors can be used to derive and compare the relative risk of FRIM across Pacific salmon fisheries, providing a measure of scalability of the factor against the likelihood of mortality risk (i.e. it is possible to measure or assess the factor in a wide range of real fisheries).
- A risk assessment tool was developed for assessing a risk score for each factor for a given fishery, and using those factor scores to generate a combined fishery-specific mortality risk score. The cumulative impact of the factors was presented as a range of mortality risk, facilitating the ability to compare the relative risk of FRIM among Pacific salmon fisheries. High correlation between the FRIM risk scores and empirically-determined estimates of mortality rates supported the validity of the approach for describing FRIM.

- Provision of updated FRIM estimates for direct use in fisheries management was not within the scope of this project. Instead, guidance on a process to use the mortality risk scores to derive numerical estimates of mortality rates was presented. The process is dependent on anchoring risk scores to mortality estimates from the literature, following a standardized approach to sourcing appropriate information and evaluating its reliability and relevance. To ensure the anchoring process is valid, further input from experts with expertise and knowledge of relevant Pacific salmon fisheries is required.
- There is inherent difficulty in inferring impacts from most FRIM-related studies due to uncertainty in the representativeness of the studies to actual fishery conditions.
- A major knowledge gap associated with most FRIM studies is the extent to which FRIM represents an incremental level of mortality over background natural mortality. There is a need for additional research efforts to refine methods for quantifying natural mortality and FRIM, and that will subsequently refine our ability to assess causal links between individual mortality events and fisheries interactions.

BACKGROUND

FRIM includes all mortality associated with fishing activities, beyond the mortality accounted for in retained catch. FRIM includes estimates of mortality for fish that encounter fishing gear but are not captured (e.g. escape mortality), that are dead upon or die during capture (e.g. on-board mortality), or that die after release (e.g. post-release mortality). Estimates of FRIM rates are used by fisheries management and stock assessment programs in the accounting of total mortality estimates of Pacific salmon.

Improved estimates of FRIM rates can reduce the uncertainty inherent in predictions of fisheries impacts and an improved understanding of factors that impact FRIM will aid in post-season accounting of both natural and fishing-related mortality. In addition, the evaluation of all types of non-retention related mortality will contribute to Canada's commitment to quantify total mortality in the Pacific Salmon Treaty.

The information provided in this review is an extensive evaluation of the primary literature on FRIM, and a general overview of the available grey literature information. Both of these can be used to form the primary evidence base for future decisions regarding the derivation of FRIM rates.

ASSESSMENT

A novel, fish-centric approach was used, focusing first on understanding factors that drive fish mortality (the factor analysis stage) and then on cataloguing literature relevant to FRIM rates (the mortality estimates stage). The overall project design is summarized in Figure 3.

Factor Analysis

A factor analysis was completed, resulting in a list of over forty factors that contribute to a mechanistic understanding of FRIM (Figure 4). Information was gathered from major review publications (e.g. Ricker 1976; Raby et al. 2015), subject area experts and directed online searches of primary literature (including more than 600 publications) to ensure newly emerging research was not being overlooked. Candidate factors contributing to FRIM were organized into four distinct categories: general fishing factors (e.g. capture time, handling time, handler technique/experience, air exposure, revival techniques); fishing method or gear-specific factors (e.g. factors relevant to net and trap fishing, such as crowding, confinement and mesh size; factors relevant to hook and line fishing, such as hook type, hook size and hooking location);

intrinsic co-factors (e.g. physiological condition, species, maturation stage); and extrinsic co-factors (e.g. water temperature, dissolved oxygen level, suspended sediment load) (Figure 4). Each factor was assessed based on its relevance to FRIM (through an assessment of its potential to adversely affect fish physiology and behaviour, and/or cause physical injury and infection), amount of available evidence, consistency of evidence, mechanism of action, scalability, magnitude of effect, and key considerations (such as relevant interactions with other factors and study limitations).

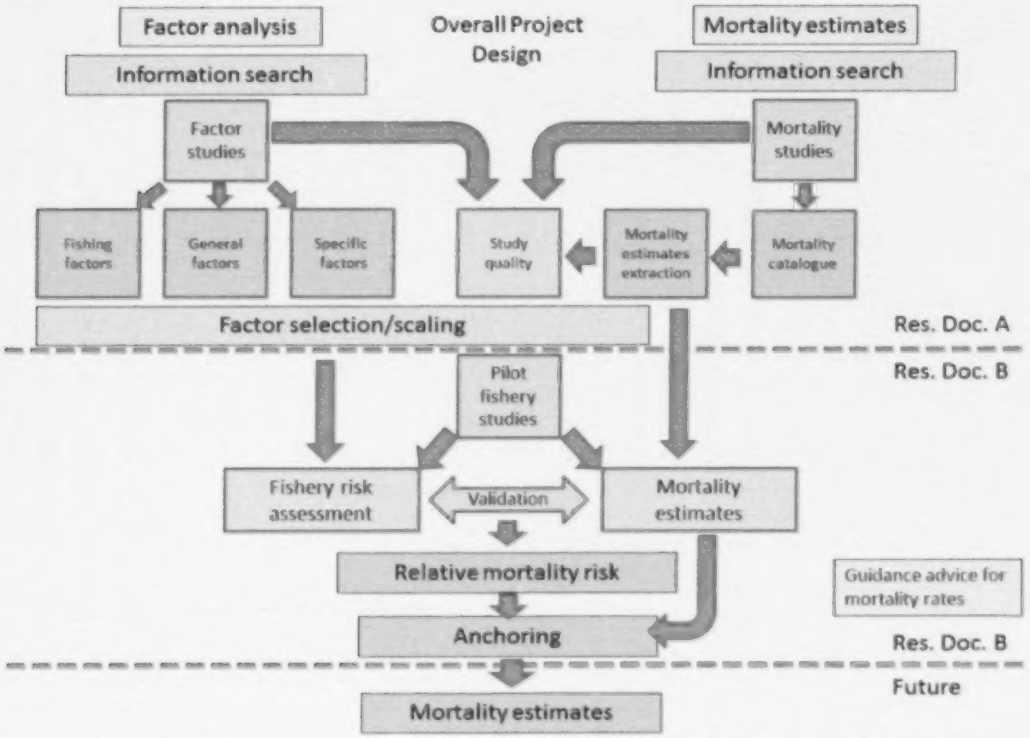

Figure 2. The overall project design connecting the two research documents with future work on generating information relevant to attaining fishing-related incidental mortality (FRIM) estimates.

Mortality Data Catalogue

An extensive and comprehensive review of published primary and grey literature related to FRIM was conducted, resulting in a searchable evidence catalogue that can be used to link factors associated with FRIM to published mortality rate estimates. Emphasis was placed on documenting the systematic process to gather mortality evidence and on identifying information to evaluate the relevance and reliability of a given study. Both will aid in the development of a process to incorporate new research results in the future; results from the current review were captured in an evidence catalogue (spreadsheet) that can easily be expanded as new research becomes available (available upon request from the lead author).

Synthesis of Key Factors and Relative Risk Scores

Information on key factors was synthesized in a manner that is useful for describing FRIM. The process to reduce the total number of potential factors down to a select group of key factors was described. Factors were assessed based on the following: quantity and quality of published

evidence; the factor's scalability to risk of mortality; the consistency of reported results (in direction and magnitude of factor effect); and a clear biological mechanism linking the factor to FRIM. Factors that had major caveats or limitations associated with their use were excluded from the short list of key factors.

The factor evaluation process led to a list of four general factors for which there is sufficient evidence to support their inclusion as a major descriptor of incidental mortality in Pacific salmon fisheries: capture time, handling, injury and water temperature.

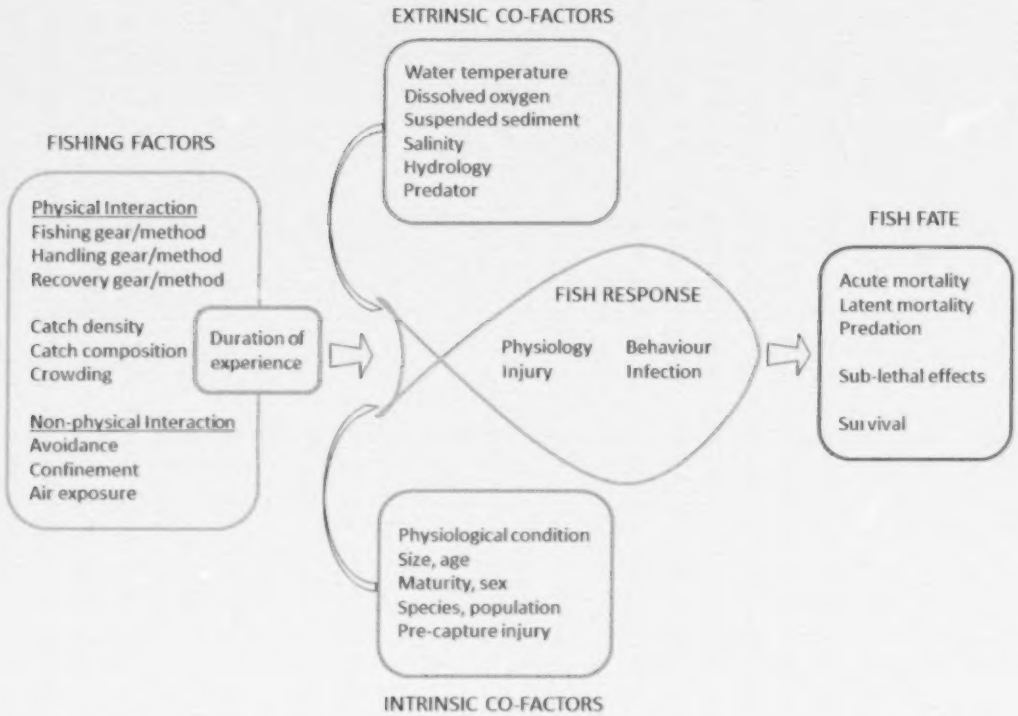

Figure 3. Conceptual diagram of factor analysis approach to understand the effects of fisheries encounters on fish mortality from a fish-centric perspective.

Additionally, predators was selected as the single context-specific factor to consider, based on the lack of ambiguity over the mechanism by which the fish's response (i.e. severe injury and death) clearly elevates with the increased risk of predation.

Finally, the key factors were scaled against the risk of mortality for both drop-off mortality and release mortality (components depicted in Figure 5), using scientific information from the factor analysis review, mortality evidence catalogue, unpublished scientific studies, and expert judgment. For each factor, its risk of adding to mortality was binned into six levels, where 1 represents a low likelihood of contributing to mortality (0-5% mortality risk), and 6 represents a high likelihood that the factor will contribute substantially to mortality (>45-100% mortality risk). The resulting relative risk scores can then be used in a risk assessment of different fisheries.

Guidance to Derive Mortality Rate Estimates

A risk assessment process to provide a combined risk score of FRIM based on an assessment of the five key factors was demonstrated. The example risk assessment was tested with numerical estimates of mortality from twelve pilot studies to demonstrate a positive correlation between mortality risk scores and mortality rate estimates for different fisheries. Note that the provision of actual FRIM estimates for specific fisheries was not within the scope of this project. The overall process involves the seven steps outlined below:

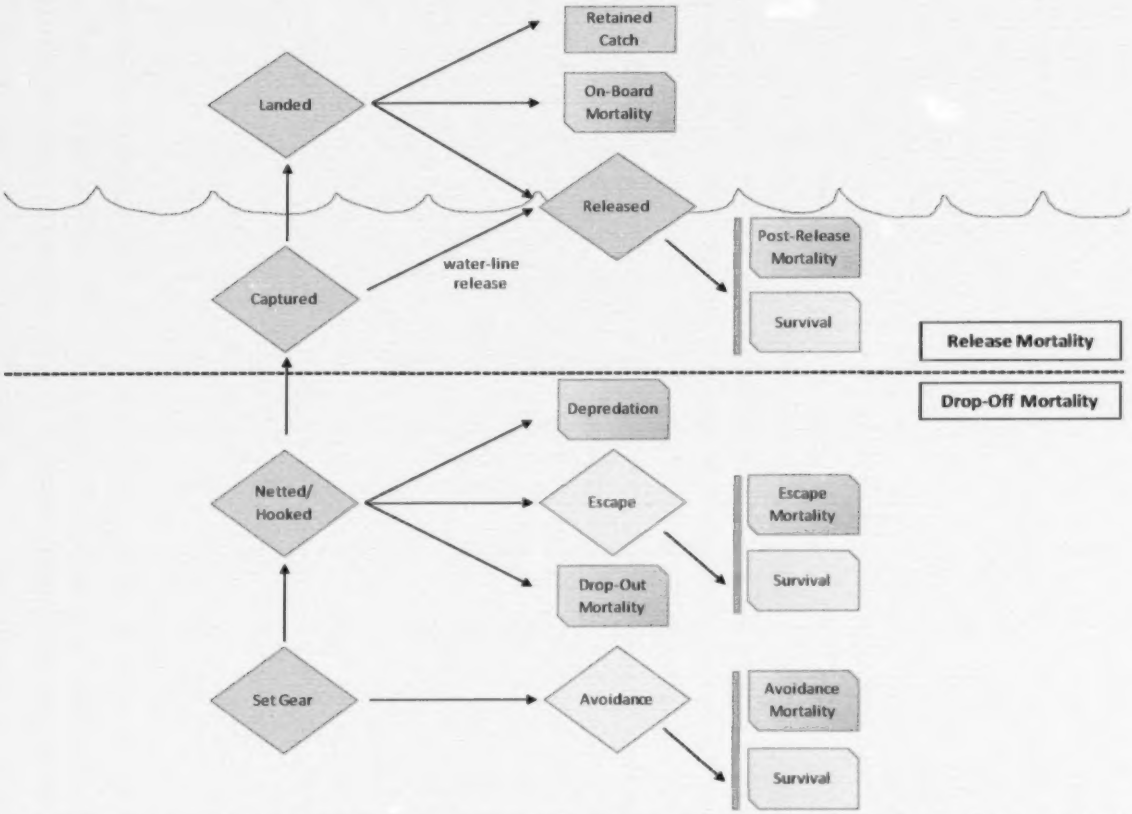

Figure 4. This diagram highlights the types of fate (all rectangles represent mortality or survival) resulting from a general fishing event. The diamonds depict the general progression of fishing activities (blue) and fish responses (yellow). The components of fishing-related incidental mortality (FRIM) are depicted by the red rectangles. (Note that the post-release mortality rectangle represents both the short-term (i.e. ≤ 24 hours) and delayed (i.e. > 24 hours) mortality components, for a total of seven FRIM components.) The escape, avoidance and post-release mortality rectangles include acute and latent mortality (e.g. predation, infection). The black dashed line partitions these seven mortality components into two general mortality risk categories–release and drop-off mortality–for potential use in management. Survival (green rectangles) can also include sub-lethal effects.

Step 1: Define the contributing sources of mortality.

Definitions of the seven components of FRIM found in various fisheries were provided (Figure 5, red rectangles). Due to a lack of sufficient published evidence at this time, the present

evaluation of FRIM combines the various pathways to FRIM into three separate categories: non-capture mortality (including avoidance, escape, depredation, and drop-out mortality), capture mortality (including fish that are dead on landing and those that die on-board) and post-release mortality. However, for the purposes of defining the risk of mortality, the latter two categories were combined.

Step 2: Characterize relevant fisheries.

Fisheries were characterized based on: information that allows fisheries management to identify or define individual fisheries within existing catch and assessment databases; spatial and temporal information to inform relevant environmental factors; and details of relevant gear or fishing methodology variants that could differentially impact fish mortality.

Step 3: Select relevant factors and ascribe factor risk scores for each fishery.

The method to select relevant factors and associated mortality risk scores was derived from the synthesis of key factors and relative risk scores (see section above). The process to ascribe the relative risk scores across fisheries was developed. Hence, the five factors can be used to derive and compare the relative risk of FRIM across Pacific salmon fisheries, providing a measure of scalability of the factor against the likelihood of mortality risk (i.e. it is possible to measure or assess the factor in a wide range of real fisheries).

Step 4: Assess cumulative impacts of multiple factors.

To account for potential cumulative impacts of multiple factors acting simultaneously, three different assumptions about factor interactions were modelled. These interactions include dominance (i.e. the mortality risk of one factor masks another – antagonistic interaction), synergistic (i.e. the overall mortality risk is greater than the expected sum of the individual mortality risks) and additive (i.e. the overall mortality risk is simply the sum of the individual mortality risks assuming no antagonistic or synergistic interactions). The results were provided to illustrate the range of potential mortality risk scores that could be generated.

Step 5: Tabulate combined risk scores for each fishery.

The risk assessment tool tabulates and presents a series of mortality risk scores using the various factor interactions outlined in the cumulative impacts section. For all factor levels (i.e. 1 to 6), both an upper and a lower mortality risk are provided. The combined lower risk estimate was calculated by combining the lowest risk percentile associated with the respective scores for all the factors. The combined upper risk estimate was calculated by combining the highest risk percentile associated with a given score for all factors. The recommended overall 'best estimates' (both upper and lower limit) of relative mortality risk for a given fishery is based on the highest value for the upper and lower dominance and additive interaction estimates (i.e. whichever value is highest for the upper and lower range for the dominance and additive interaction estimates).

Step 6: Validate relative risk scores among fisheries.

To validate the risk assessment tool, an example was provided using data from twelve pilot studies and one researcher with expert knowledge of the key risk factors within each study (the twelve studies were used to simulate separate "fisheries"). The range of mortality risk scores derived from the risk assessment of the pilot studies was contrasted against the range of observed mortality estimates provided by those studies. A high rank and linear correlation between the mortality risk scores and the mortality estimates supported the validity of the approach.

Step 7: Guidance on method to anchor risk scores to estimates of mortality.

Advice was provided for anchoring relative mortality risk scores against actual mortality rate estimates. Ideally, anchoring would be provided by a subset of studies that have been conducted under realistic fishery conditions and that have generated direct estimates of mortality over appropriate time periods (e.g. release mortality greater than 96 hours). The main challenges to selecting relevant key studies are: the ability to estimate natural mortality, the degree of fishery realism provided by the study, and the length of mortality response period assessed.

Sources of Uncertainty

Many knowledge gaps and sources of uncertainty were identified through this review process. Key sources of uncertainty are outlined briefly here.

- There is a lack of information to quantify the combined effects of the five key FRIM factors (e.g. potential synergistic interaction between higher temperatures and injury). Further, the potential for cumulative effects on individual fish subjected to multiple fisheries interactions also presents an important knowledge gap.
- A key difficulty in synthesizing the body of literature related to FRIM is the inconsistent use of terminology to describe different types of mortality. This project provides a basis for standardization of the terminology which will aid future research and mitigation efforts, but does not help interpret or elucidate differences among existing studies in the literature.
- Very little evidence currently exists in the primary literature to fully quantify the impact of predation across different fisheries and species, even though the biological mechanism of depredation and post-release predation on Pacific salmon is clearly understood.
- Pacific salmon are diverse and vary in their physiology, behaviour, and morphology among species, populations, sexes, and individuals. Comparative species- and population-specific studies will provide information on the inherent variability of FRIM. Notably, there is a lack of information at present in the primary literature on Pink and Chum Salmon in general, as well as results for North Coast British Columbia populations of any Pacific salmon species.
- Water temperature is a major modifier of mortality through a variety of physiological and disease-related mechanisms and much remains unknown about its ability to mediate fish response to fishery encounters.
- There are practical and scientific limitations to the methods currently available for estimating all components of drop-off and release mortality, including biases introduced through captive observation studies and tagging/biotelemetry studies.
- Uncertainty remains in the process to anchor relative risk scores derived through this work to actual estimates of FRIM rates for eventual use in stock assessment and fisheries management of Pacific salmon. Additional work will be required to establish and assess the validity of this component of the process.

CONCLUSIONS AND ADVICE

This review of fishing-related incidental mortality (FRIM) for Pacific salmon provides a series of foundational steps towards a better biological understanding and an overall risk assessment of FRIM. These include: a comprehensive review of factors linked to FRIM; a mortality rate evidence catalogue that amalgamates relevant mortality estimates; a synthesis of five key factors that are most relevant to derive and compare relative risks of FRIM across Pacific

salmon fisheries; a risk assessment tool to combine the impacts of the key factors into relative mortality risk scores; and a discussion of possible anchoring methods to translate relative mortality risk scores into absolute mortality rate estimates. The provision of absolute FRIM rate estimates for individual fisheries was not within the scope of this review.

- This work provides a robust and transparent method for assessing the relative risk of FRIM across Pacific salmon fisheries.
- This type of mechanistic assessment (i.e. with a primary focus on fish response) to describe FRIM provides opportunities to highlight and prioritize areas to mitigate FRIM risks. For example, if actions to reduce air exposure are proposed in fisheries where the present relative risk is found to be high, handling requirements that reduce air exposure could lead to direct reductions in FRIM risks.
- Accurate, objective estimates of FRIM rates are inherently difficult to obtain. Even when such estimates are available from individual studies, the limitations of study design make it necessary to interpret the studies that generate them with caution and require informed consideration of the context-specificity and possible biases associated with them.
- Very little published research currently exists to allow for quantification of drop-off mortality rates.
- The total impacts of FRIM are under-estimated by the use of short-term mortality assessments (i.e. mortality assessed within 24 hours of the interaction with a fishery). Where possible, use of longer-term mortality estimates is recommended.
- Continued monitoring and research of the five key factors (e.g. water temperature, air exposure) and how they interact is recommended. Given that water temperatures are dynamic and are expected to continue to rise with climate change, additional research related to water temperature and the mechanisms underlying incidental mortality is a high priority. For example, the importance of understanding the interaction between water temperature and injury will be relevant for both pre-season planning and post-season accounting.
- Additional research and monitoring of fishery-specific factors are recommended to improve the information base available to characterize FRIM for certain fisheries (e.g. census information on injuries, handling practices). The inability to accurately describe the conditions of realistic fisheries limits the utility of risk assessment approaches for stock assessment and fishery management purposes.
- This project demonstrates in principle the utility of the risk assessment tool. More work and feedback is required before the proposed risk assessment tool can be applied for certain uses in management (e.g. to update Integrated Fisheries Management Plan tables). Recommended next steps include engaging in discussion with a wider audience and incorporating monitoring and reporting systems to provide information.
- A proposed anchoring method was outlined to link relative FRIM risk scores to absolute mortality rate estimates. Further work is recommended to test and refine the method prior to broader application; a case study on the potential utility of the method for translating relative FRIM risk into actual FRIM rates is scheduled for future CSAP review.
- There are multiple uses of FRIM in fisheries management and stock assessment that vary in application across different fisheries. This variability results in a multitude of additional information requirements that need to be addressed before model outputs that require FRIM

can be calculated. These information requirements can include estimates of stock-age composition, encounter rates, fleet profiles, and compliance rates.

- There is inconsistent use of various terms throughout the published and grey literature. The interpretation of variable definitions and categorizations of fishing factor details and mortality outcomes is difficult (e.g. different sectors have developed and use similar terms in very different ways, and very different terms in similar ways). In the future, adopting a standardized set of terminology will aid in the direct comparability of future research efforts and possibly allow for the disaggregation of some FRIM components leading to further improvements in the accuracy of FRIM estimates.
- Owing to similarities in their content and approach, and in order to provide departmental consistency, it is recommended that future work related to FRIM and the recently-developed Catch Monitoring Risk Assessment Framework (terminology and methods) be aligned and linked, wherever possible.
- Continued development and validation of vitality indices (i.e. surrogate assessment tools that can be used to reliably predict release mortality) along with a rapid injury assessment tool to predict FRIM in the field could assist in the ability to generalize and streamline the process to assess FRIM risks for release mortality.
- As new information becomes available (with respect to both emerging research and changing fisheries practices), it will be necessary to update the factor analysis, mortality evidence catalogue, factor scoring, and risk assessment tool accordingly. The evidence catalogue, which was used to inform the key factors that affect FRIM, has been designed so that it can be updated and reviewed as new findings from salmon and other species become available.

SOURCES OF INFORMATION

This Science Advisory Report is from the June 6-7, 2016 regional peer review on the Review and Evaluation of Fishing-Related Incidental Mortality for Pacific Salmon. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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